Table of Contents



- Thermal control system overview
- Background on Technology Readiness Level
- NASA Office of Chief Technologist Solicitation Overview
- Variable Heat Rejection Technologies
 - Electrochromics
 - Freezable Radiators
 - Digital Radiators
- Future Work and Overview

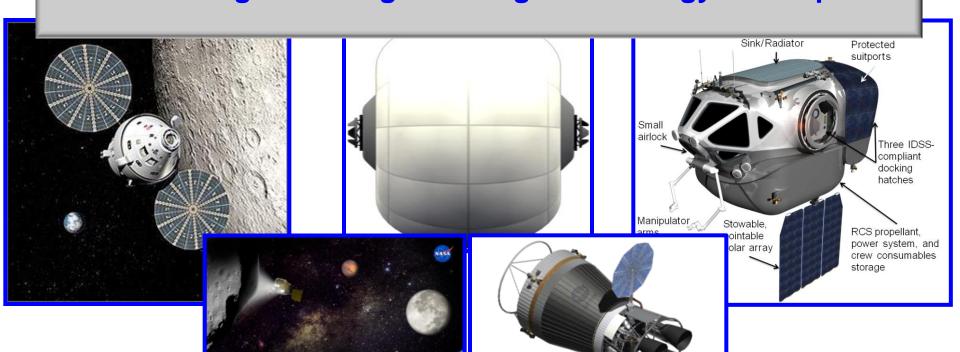




Variable Heat Rejection Technology – Advanced Thermal Team Objective



Primary project objective is to mitigate key mission risks and address design challenges through technology development



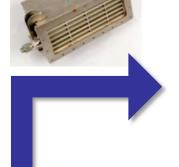
Important secondary benefit:

Project personnel gain "real life" experience through entire development process (analysis, design, fabrication, test, documentation, etc...)

Variable Heat Rejection Technology – Thermal Control System Overview

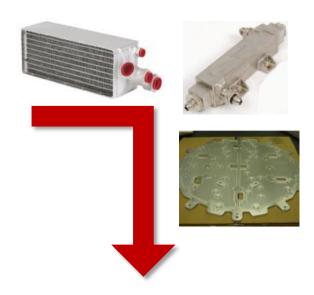






Heat Acquisition

Coldplates, Heat Exchangers, etc...



Heat Rejection

Radiators, Evaporators, Sublimators, Phase Change Materials, etc...







Heat Transport

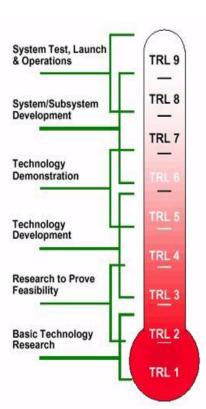
Pumps, Plumbing, Fluids, Heat Pipes, Heat Straps, etc...

Variable Heat Rejection Technology – Technology Development Process



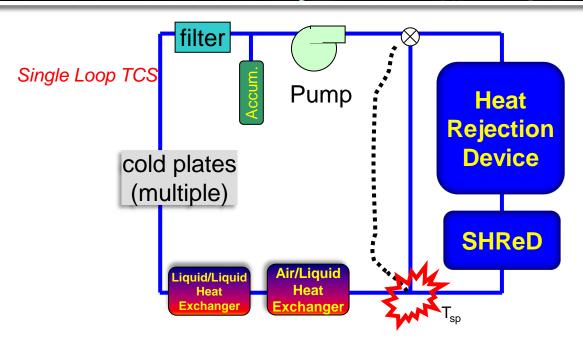


- 1. Coupon level bench top tests
 - Better understand driving physics and key development challenges
 - Fairly "crude" laboratory experiments
 - Develop correlated models
- 2. Fabricate & test Engineering Development Unit (EDU)
 - Scaled component addressing key development issue(s)
- Design and analysis cycle
 - Assess EDU data, correlate performance models, recommend improvements, write requirements, & design prototype hardware
- 4. Fabricate & test prototype hardware
 - Test hardware as a "stand-alone" component
 - Integrate prototype hardware into a ground-based integrated systems test
 - Several technologies achieve TRL 6 (fluids, heat exchanges, evaporators, cold plates)
- Identify technologies requiring ISS demonstration (sensitivity to space environment) & fabricate prototype hardware
 - Remaining technologies achieve TRL 6 (radiators, PCM heat sinks)



Variable Heat Rejection Technology – Ideal Thermal Control System





- Ideally, an active thermal control system would be a simple single loop system
- An ideal thermal control system would incorporate
 - Human compatible thermal control fluid that has a low freeze point and excellent thermal performance
 - Radiator that can turndown the amount of heat being rejected to space from its designed maximum capability
 - Small low-weight heat exchangers that are highly efficient
 - Supplemental heat rejection devices (SHReDs) that are low-weight and have an efficiency of unity.

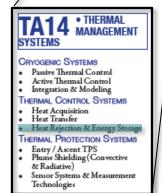
Variable Heat Rejection Technology – Overview of OCT's Solicitation



- NASA, NRC, and other public forums helped formulate a strategic space technology roadmap for space exploration.
 - 14 Technical Areas (TA) were sighted with specific areas of focus within each TA
 - Passive, Active, and Aero thermal control were noticed at various level of priorities to enable space exploration.



- Highest priority within the Thermal Control Systems part of Thermal Management Technical Area 14 was Heat Rejection and Energy Storage.
 - Variable Heat Rejection is noted as a high priority to enable efficient and reliable human rated thermal control for future exploration vehicles.
- NASA's Office of Chief Technologist Game Changing Division has come out with a solicitation requesting technology development in the area of variable heat rejection
 - Solicitation number is NNL12A3001N Appendix C Due Sept 6th 2012 (https://nspires.nasaprs.com)

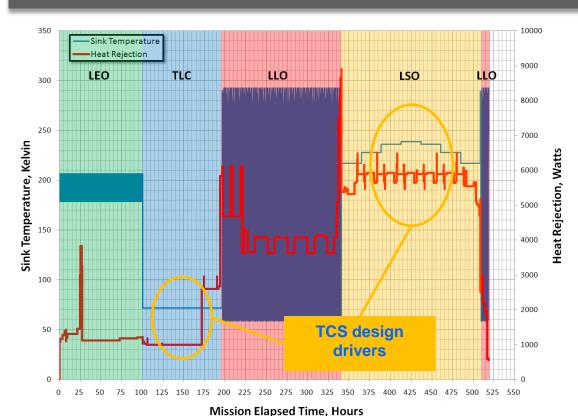


Variable Heat Rejection Technology – Variable Heat Rejection Technologies



Problem Statement:

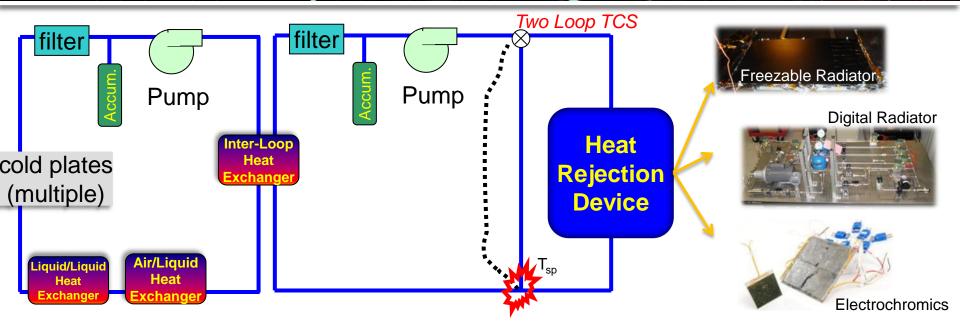
Exploration vehicles such as the Multi Mission Space
Exploration Vehicle and Deep Space Habitat are expected to
have thermal control systems (TCS) that require the
capability to vary the amount of energy rejected with minimal
system impact



- The Thermal Control System is typically sized for the largest continuous heat load and environmental sink temperature
 - Large radiator area is derived from this requirement (lunar surface operations or "LSO" in graph)
- The same thermal control system must operate at lower heat loads and sink temperatures (Trans-Lunar Coast, or "TLC" in graph) – requiring a high turndown in heat rejection
 - Due to large radiator area, fluids may freeze
 - Fluids such as Ammonia or Freon® are used in TCS.
 - Low-freeze fluids are toxic to crew members pushing TCS to a two-loop architecture
- This design challenge has been seen in numerous vehicles previously designed and currently being designed.

Variable Heat Rejection Technology – Variable Heat Rejection Technologies



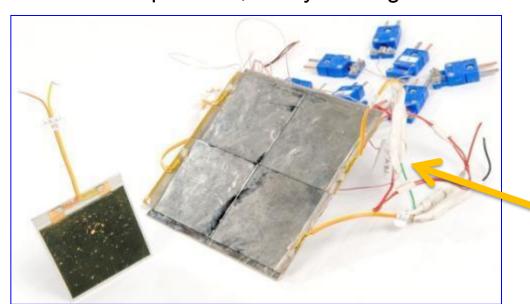


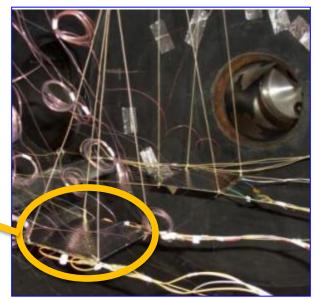
- High turndowns drive TCS to a dual-loop architecture
- Second loop increases TCS mass by ~25%
 - Additional pump(s), accumulator, inter-loop heat exchanger, larger radiator, less effective heat transfer fluid, etc...
- Single-loop architecture has improved reliability and maintainability
- Previous Development Efforts Include:
 - Electrochromic Radiators
 - Freeze-Tolerant Radiators
 - Digital Radiators

Variable Heat Rejection Radiators – Electrochromics



- Developing three promising radiator technologies to enable single loop TCS:
 - 1. Electrochromic Radiator (ERAD)
 - Actively changing the radiator's infrared emissivity by applying a small voltage
 - Changes the rate at which energy is rejected from the surface
 - Performed analytical studies to determine the required emissivity turndown ratio (3.9 – 12)
 - Completed two thermal vacuum tests using ERAD coupons to assess performance metrics (turndown ratio, ability to perform in vacuum and at temperature, ability to integrate with radiator materials, etc...)

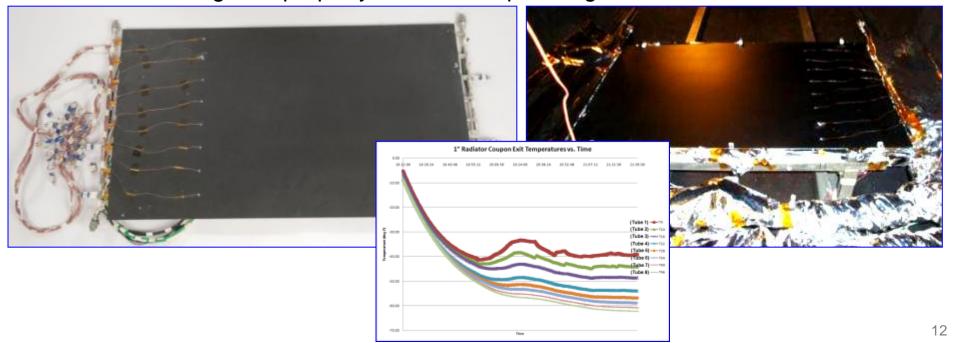




Variable Heat Rejection Radiators - Freezable Radiator



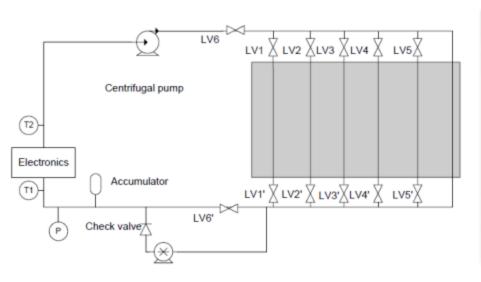
- Developing three promising radiator technologies to enable single loop TCS:
 - 2. Freezable Radiator (FRAD)
 - Allow radiator fluid to freeze and thaw in a predictable manner based on the radiator geometry (fin spacing, tube lengths, etc...)
 - Reduces the participating radiator surface area
 - Performed two thermal vacuum tests using simplified test articles to produce empirical data for model correlation
 - Performing fluid property studies and planning next thermal vacuum test

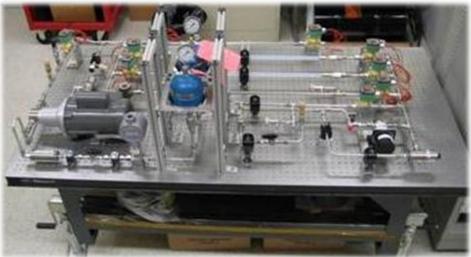


Variable Heat Rejection Radiators – Digital Radiator



- Developing three promising radiator technologies to enable single loop TCS:
 - 3. Digital Radiator (DRAD) JPL Lead Task
 - Actively drain radiator tubes using gear pump
 - Reduces the participating radiator surface area
 - Completed design and master equipment list for full scale radiator system
 - Designed, fabricated, and completed two bench-top tests evaluating evacuation methods and demonstrating proof of concept





13

Variable Heat Rejection Radiators – Future Work and Conclusions



- Active Thermal Control is in a new era of technology development were focus is being driven towards thermal control systems that can withstand variable heat loads and environmental sinks
 - Highly reliable and mass efficient designs.
- Advanced thermal project is currently looking into the following development efforts
 - Loop Heat Pipes
 - Reformulation of Thermal Control Fluids
 - Freeze Tolerant Radiator
 - Electrochromics
- Project is constantly looking for strategic partnerships